Myrick & Sterling

Corona loss between wire and ground

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CORONA LOSS BETWEEN WIRE AND GROUND

BY

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

GEORGE HAROLD MYRICK and JAMES DONALD STERLING

ENTITLED CORONA LOSS BETWEEN WIRE AND GROUND

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

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INTRODUCTION

The tendency toward the use of higher voltages in long distance transmission of power is rapidly increasing. Therefore electrical engineers are having the study of the phenomena of high voltage transmission forced upon them.

One of the most important, and most interesting of these phenomena is corona. When high voltages are used the conductors glow with a pale blue light which in the dark is plainly visible, and it is to this that the term corona has been applied. Previous investigations show that corona constitutes a waste of power, and the object of this thesis was to find a means of measuring this loss, and show that the method is feasible.

GENERAL THEORY.

When high voltage transmission of power is used the air surrounding the conductors is subjected to a strain caused by the flux of electric force through it. When the voltage reaches a critical point this strain becomes great enough to break down the air, and causes envelopes of conductive atmosphere around the wires. At this point there appears a pale blue light around the conductors caused by a leakage of current which is of the nature of a static discharge.

This leakage, which is known as corona, varies with the size of the wire, distance to ground, barometric pressure, and condition of the

wire, and at extremely high voltages constitutes a considerable loss of power. Thus it becomes a matter of importance to be able to determine its magnitude.

A transmission line was constructed, and three methods of measuring this power loss were tried.

First, wattmeter readings were taken on the low side of the transformer.

Second, wattmeter readings were taken using the voltage on the low tension side, and the current on the high side.

Third, the current and voltage waves were determined by means of an oscillograph, and the power found from the curves by multiplying corresponding values of current and voltage and integrating the power waves thus obtained.

DESCRIPTION OF APPARATUS AND CONNECTIONS

The apparatus which served as a transmission line consisted of two poles placed about fifty feet apart, and supplied with adjustable cross-arms suspended from the top of the poles. Twelve ropes were stretched between the adjustable cross-arms, and a number eight copper wire was hung by catenary suspension under each of the ropes. All of the wires were connected in series, and suspended by means of silk thread, the total length being six hundred feet.

The transformer which was used to step-up the voltage has a capacity of 10 K.W. and its ratio to transformation is 440 to 100000. It was designed to stand a pressure of 100000 volts between terminals with the neutral grounded. It was in dealing with the transformer that the first serious difficulty presented itself. This was due to the

fact that in this thesis work it was necessary to ground one terminal of the transformer, thus making the strain on the high potential coil much greater. The ground to neutral was removed, and the transformer was tested with one terminal grounded. It was then found that sparking between the coils and the case would occur at moderately high voltages. To remedy this, the coils were lifted from the case, and all of the exposed portions of the coils were wrapped with tin foil to increase the diameter of the conductor, and thus cut down the danger of sparking across. The small size of the terminals leading out from the case was also considered a source of weakness in the transformer, so they were removed and larger ones substituted; and in the case of the terminal to which the line was connected a copper rod about three-quarters of an inch in diameter was used. In this way voltages between 70,000 and 80,000 volts were made available between wire and ground. It was also considered best to eliminate corona as much as possible on that part of the apparatus leading out to the line.

The best way to accomplish this is to enlarge the diameter of the conductor, and to remove all metallic corners or points. Therefore, a two inch iron pipe was used to bring the terminal out of the transformer room and from this pipe to the line a No. 3 standard wire was used on which the corona effect was small.

The connections during the test were made as shown in the diagram. The primary voltage was obtained from a motor-generator set in the Electrical Laboratory, and the voltage was adjusted by means of rheostats in the field of the alternator.

The voltage impressed between line and ground was determined by taking readings of the primary voltage and multiplying them by the

ratio of transformation.

The oscillograph used was a General Electric instrument, and it was used to get the current and voltage waves in their correct relations to each other.

To get the voltage wave, a small auxillary coil of about twenty turns was wound around the core of the transformer, and the terminals of this coil was connected through some lamps to the oscillograph. It was assumed that the E.M.F. induced in this coil was in phase and directly proportional to the E.M.F. of the high voltage coil of the transformer.

To get the current wave, one terminal of the transformer was grounded through the oscillograph and a mil-ammeter of the Whitney type, so that the total current flowing in the high voltage coil went through the transformer, and was read on the mil-ammeter.

With the transformer connected in this way it may be easily seen that if by some oversight the switch in the ground circuit should be left open when voltage was applied to the primary, there would be a potential difference equal to one-half the terminal voltage of the transformer between this terminal and the ground. This would put the person working with the oscillograph in great danger.

To obviate this a spark gap was placed in another circuit between the terminal and the ground as shown in the diagram.

This spark gap consisted of a piece of paper between the ends of the two brass rods. With this spark gap included in the connections a high voltage would puncture the paper and leave the transformer terminal grounded; thus eliminating the danger to the operator. The fields of the oscillograph were excited from a 110 volt D.C. circuit.

With these connections simultaneous oscillographic records were

taken of voltage and current for varying voltages and different heights of the wire from the ground.

DISCUSSION OF METHODS AND RESULTS.

Method of taking Wattmeter Readings on low side of Transformer

This method of measuring the losses was first tested for the reason that if it proved sufficiently accurate it would give the quickest results. A 10 K.W. wattmeter was connected in the low tension side of the transformer, and with the line connected readings were taken of the power delivered to the transformer at various voltages.

The line was then discontinued, and readings were repeated at exactly the same voltages as before. Thus it was thought that the difference in the two readings at the same voltage might give the value of watts lost on the line. At 75000 volts on the line the wattmeter reading was 4000 watts with the line connected, and 3900 without the line. This would leave a loss of 100 watts which might be charged to the line.

It was easily seen that this method has too great a chance for errors to enter into the results. The instrumental error of the average wattmeter is from one to two percent. Then there are also external errors, such as errors due to the reading of the wattmeter which would probably bring the possible error in any reading up to two percent. A two percent error in the 4000 watt reading would give an eighty percent error in the result while there is the same chance for error in the 3900 watt reading which might add up with the other error

and make the result of no practical value whatsoever.

Method of taking Wattmeter Readings using Primary Voltage and Secondary Current.

It was quickly found that this method was of no value. The power measured by the wattmeter would be in the same ratio to the true power as the ratio of transformation. This means that if 100 watts were lost on the line, the wattmeter would read approximately one-half watt. A large error would be introduced in the reading, and it would require an especially designed wattmeter to read the power with any degree of accuracy, and at the same time stand a pressure of from 200 to 400 volts on the pressure coil.

OSCILLOGRAPH METHOD

From a study of the previous methods it was thought that a possible means of determining the power loss was to accurately measure the line current, obtain the voltage by means of the ratio of transformation, and find the power factor by means of the oscillograph.

The oscillograph was, therefore, onnected as has been previously described, and records of current and voltage waves in their proper phase relations to each other were taken at varying voltages and different heights of the wire from the ground. Readings were taken of line current and primary voltage. It remained then to investigate the curves, and obtain the value of the power lost from them.

In Order to do this accurately it was necessary to enlarge the curves which was accomplished by means of a projection lartern.

A glass plate was put on each side of the film to keep it from burning, and also to make it lay flat. The outline of the curves was thus thrown on a large sheet of coordinate paper and was traced in with a pencil. Eight records were enlarged in this way, four of which represented a variation of voltage with the line disconnected, and four a variation of voltage with the line connected, and at a distance of two feet seven inches from the ground. These curves were then investigated, and it was found that no reliance could be placed on the results obtained for the values of the power loss. In fact it was found that for some cases the values of power lost were greater with the line disconnected.

There are two probable causes for this inaccuracy. The first one is, that by the time the curves had been traced the films had become hot enough to wrinkle, and thus throw the curves out of shape; and and since one curve was drawn at a time their phase relation would be affected.

The second cause for inaccuracy, was in the investigations of the curves. Due to the comparatively large capacity current when the line was so close to the ground, the difference between the summations of the positive and negative volt-ampere calculations was only about five percent of either summation. Hence a two percent error in either summation would cause an error of 40 percent in the value of power loss obtained.

To obviate these difficulties, four records were taken to a photographer, and enlarged. The sensitized paper used in this method made the intense light of the arc unnecessary. These four curves were all taken at the same voltage but at different heights of the wire

from the ground, thus making it possible to determine whether or not the curves could more accurately be worked out with a smaller capacity current.

The results obtained from these curves were more satisfactory. In the investigation, the value of watts lost was found to be about 35 percent of either summation of volt ampere calculations with the line 7 feet 6 inches high. At a height of 10 feet 5 inches this percentage was raised to 50. Thus it is considered probable that with the line at heights above 7 feet from the ground, this method of enlarging the curves, and investigating them can be made practicable.

Three oscillograph records were investigated by the final method, and curves drawn using watts lost, and secondary current as ordinates, and height from ground as abscissas. The watts lost and current includes also the leakage in the transformer. The curves show a decrease of current with an increase of distance to the ground, but show an increase of watts lost. This is probably due to the fact there was more dust settlement on the insulation, and wire at the greater heights. The curves were taken a number of days apart, starting with the smallest distance to ground, and increasing the height each time. Thus more time was given for the dust to settle as the height increased, and as the air was smoky the insulators were probably affected to a great extent by the dust. Although the actual current decreased, the power current increased. This means that the capacity current decreased more rapidly than the power current increased giving a smaller total current each time.

CONCLUSIONS.

All of the apparatus used for this thesis work, with the exception of the oscillograph, was very rough. The wire was suspended by means of silk cords, which with a variation of moisture and dirt would allow of a variation of leakage through the suspensions. The leakage loss in the transformer varied from about 25 to 50 percent of the total loss.

The short length of the transmission line was another handicap, because it did not give the best working conditions for the oscillograph. The tension in the vibrating loop had to be lessened considerably below its normal value so as to give a good amplitude to the current wave, thus giving rise to possibilities of error in the wave shape.

These difficulties may, however, all be partially removed by means of better apparatus. The silk thread suspensions can be replaced by insulating material which can be cleaned from moisture and dirt before measurements are taken. To determine the power lost due to insulator contact with the wire, the insulators may be varied in number per unit length of wire and a curve drawn between watts lost and the number of insulators. Then if the curve is extended until it cuts the axis, the value of the ordinate will give the loss with no insulators for that voltage.

The excessive leakage in the transformer was probably due to the fact that small wire was used for the high voltage coils. The static field around such a wire is liable, at voltages of from 50000 to 80000, to break down the oil as it does the air. Evidences of this were

given during the tests. At voltages of about 70000 or higher a white smoke would rise from the transformer if the voltage was held for any considerable length of time, thus giving evidence of heating in the coil.

A larger transformer wound with heavier wire would, therefore, eliminate much of the corona in the transformer, and thus cut down much of the leakage loss and also the likelihood of breakdowns.

From a study of the methods and results, it seems very probable that with improved apparatus, and a longer transmission line, measurements of corona loss can be made that will be within the limits of allowable error.

APPLICATION OF DR. BERG'S FORMULA FOR CORONA LOSS

Dr. Berg's formula for the loss due to corona between wires in a three phase line and the values of the constants are as follows:

K.W. per 100 miles = $Kde^{a(E - K_1 Bd\log_{10} D/d)}$

K, a and K_1 are constants.

e = the base of Naperian logarithms.

d = diameter of wire used in inches.

E = kilowatts.

D = distance between wires in inches.

$K = 31$; $a = .11$; $K_1 = 6$.

In applying this formula to find the loss between wire and ground the following alterations were made. The value of voltage was doubled and twice the distance to the ground was used for D.

Values were calculated for the different heights at a voltage of 72700 and the following results were obtained.

Height in inches	31	91	123

Loss in watts	3167	688	665

These values for the loss are too large to be at all probable, and they do not check with the experimental values obtained. It is therefore considered that the alterations made in applying the formula are not correct.

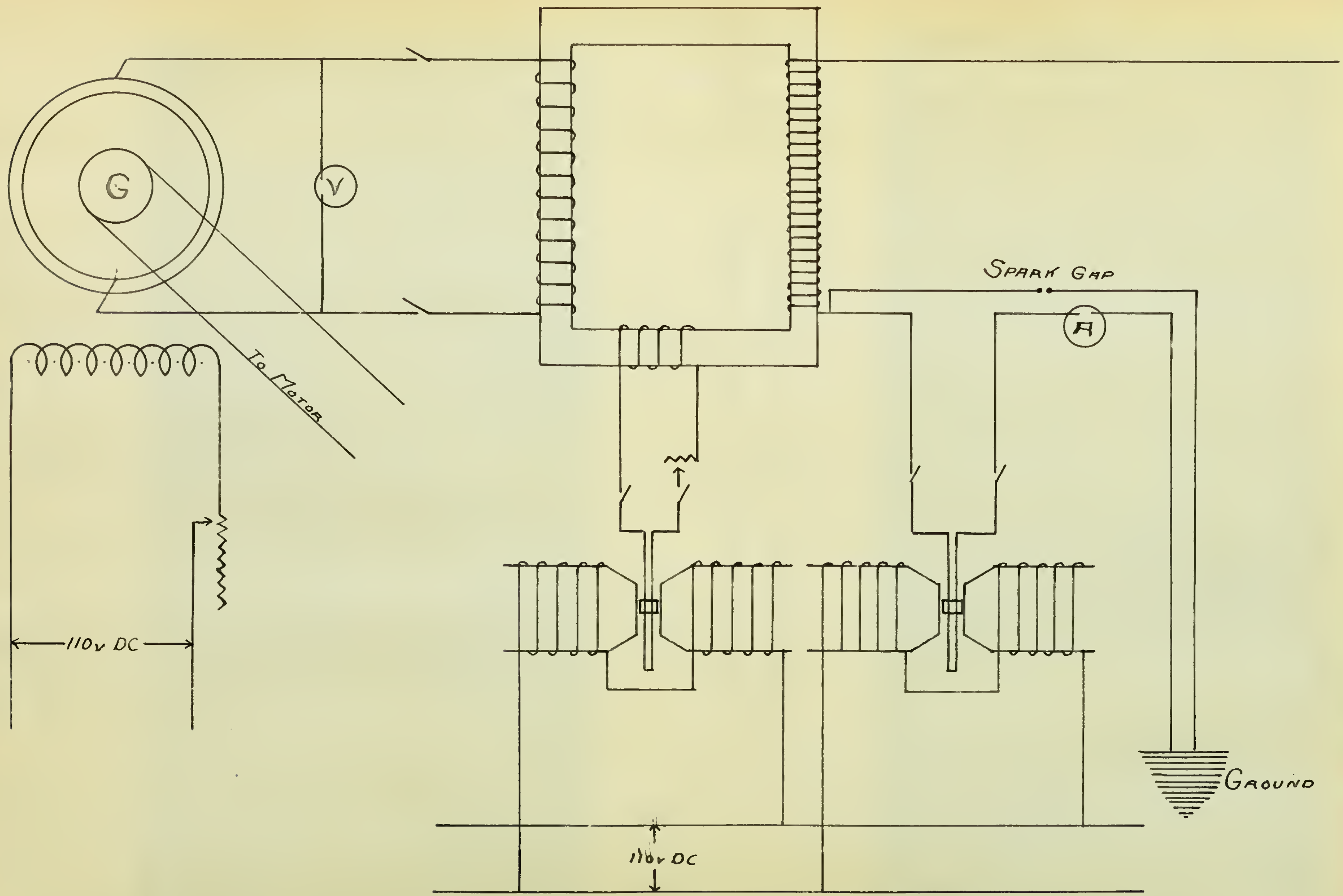
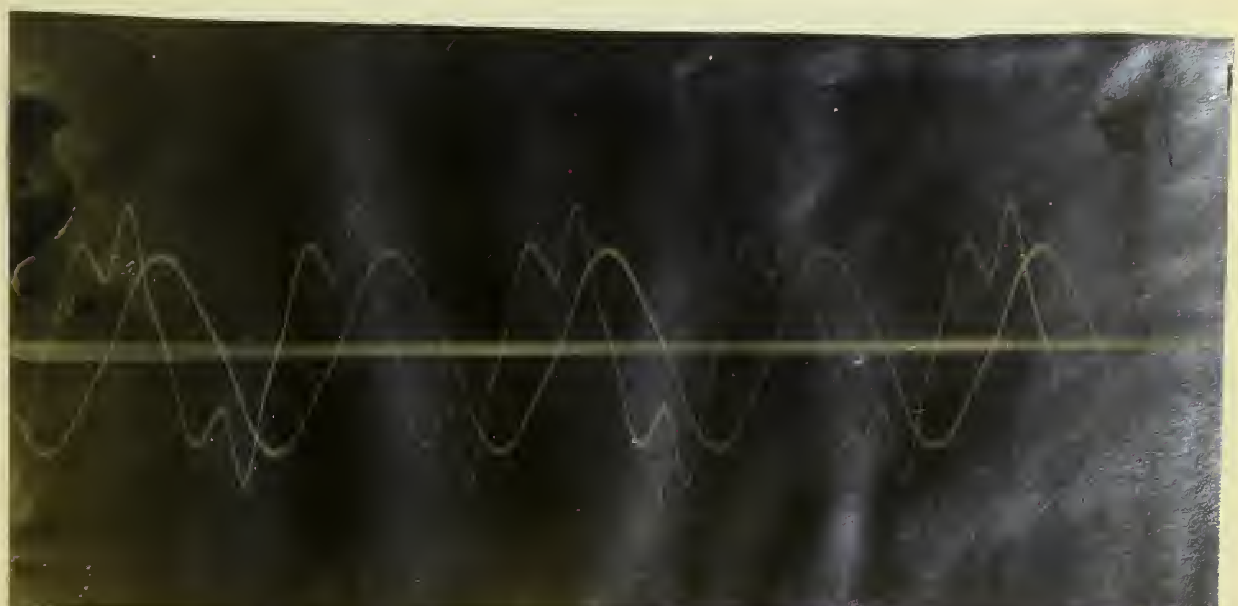


Diagram of Connections.

OSCILLOGRAPH RECORDS

Height of Wire 2 Feet 7 Inches
45,500. Volts .023 Ampers.

Height of Wire 2 Feet 7 Inches
59,200 Volts .027 Ampers.

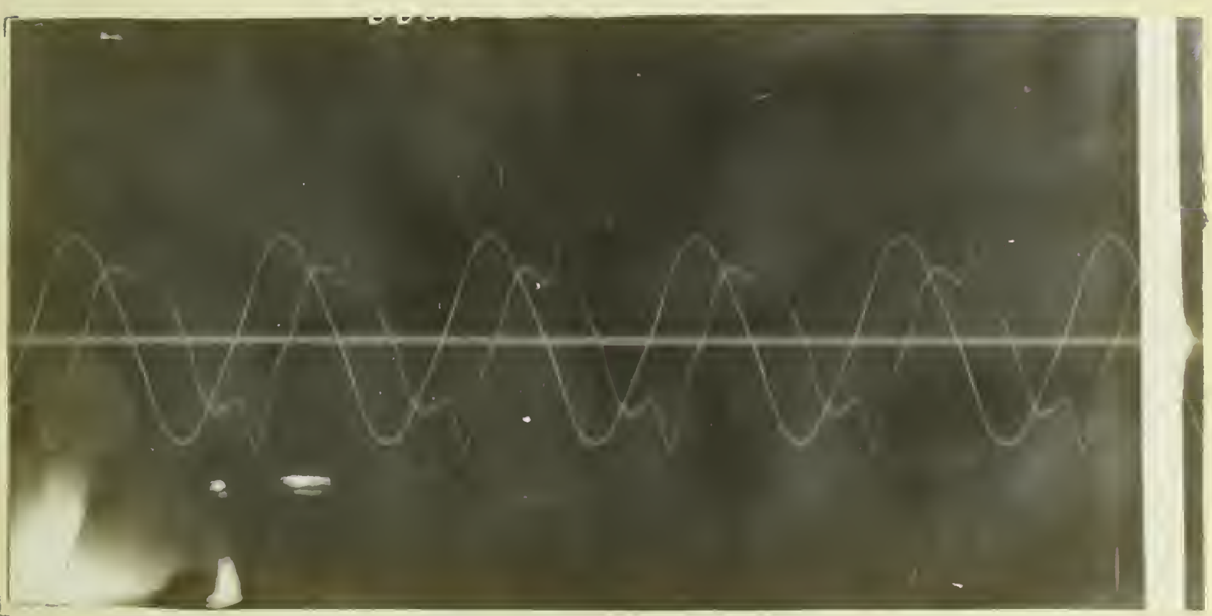


Height of Wire 2 Feet 7 Inches
68,300. Volts .031 Ampers

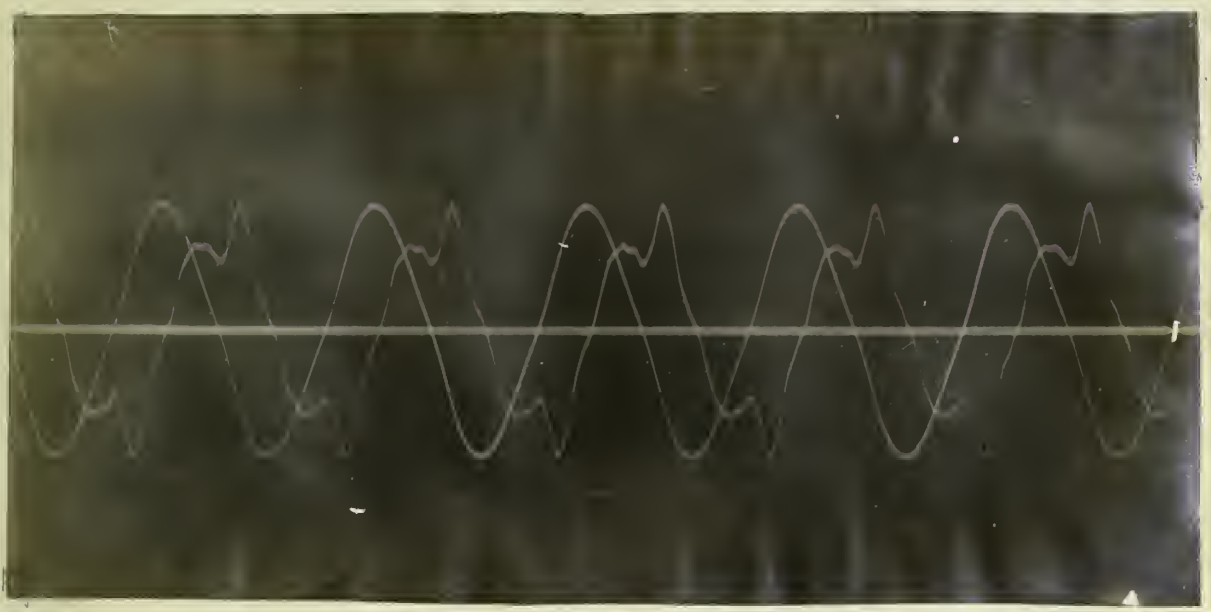
Height of Wire 2 Feet 7 Inches
72,700 Volts .033 Ampers

Height of Wire 7 Feet 5 Inches
45,500 Volts .01575 Ampers.

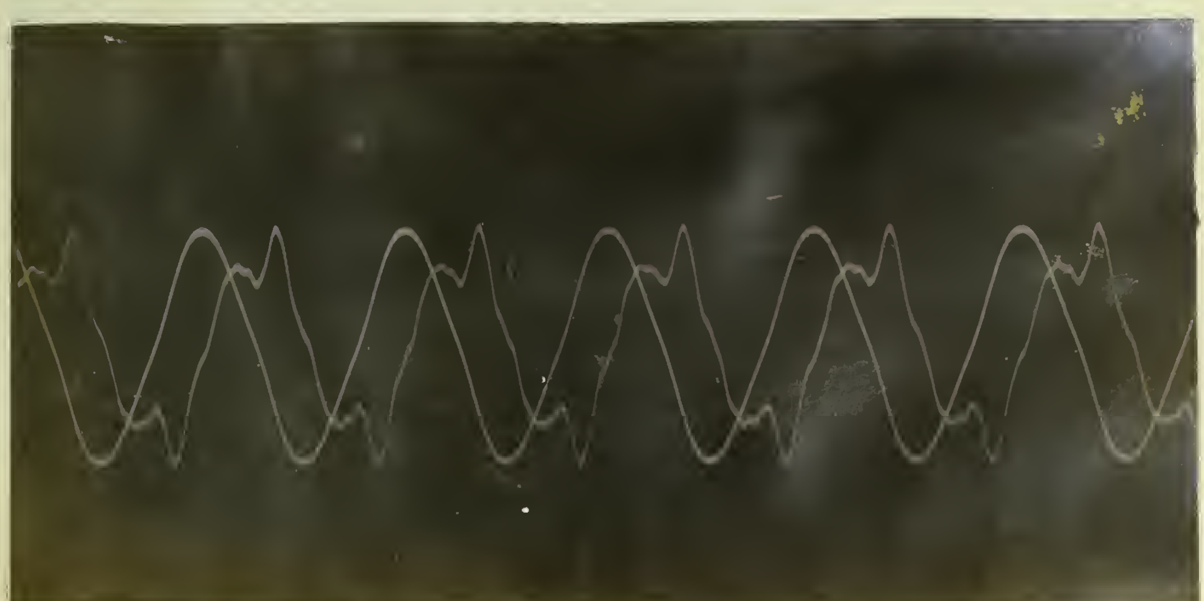
Height of Wire 7 Feet 5 Inches
59,200. Volts .02125 Ampers



Height of Wire 7 Feet 5 Inches
68,300. Volts .0235 Ampers

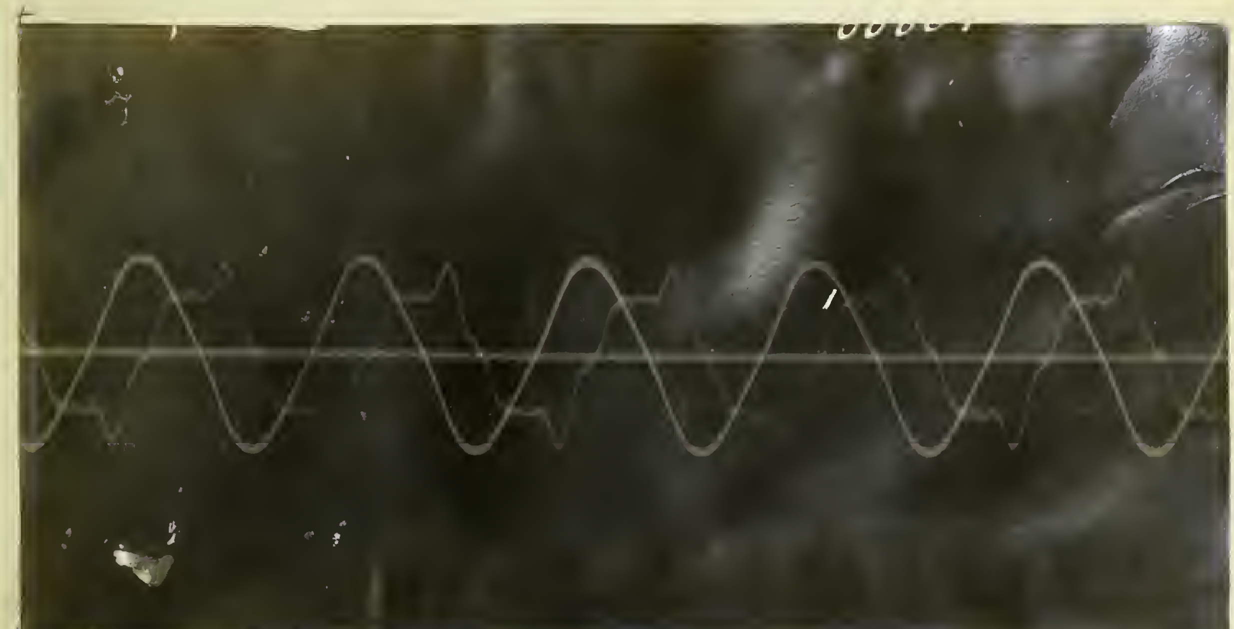


Height of Wire 7 Feet 5 Inches
72,700. Volts .025 Ampers



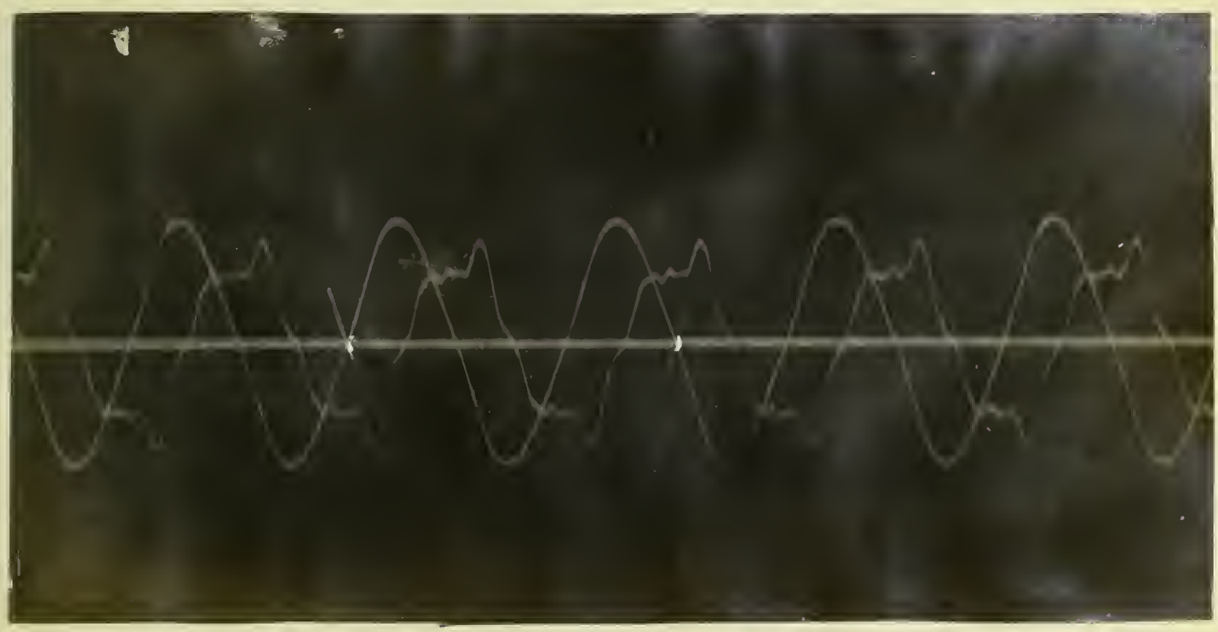
Height of Wire 10 Feet 3 Inches
46,500 Volts .01375 Ampers

Height of Wire 10 Feet 3 Inches
59,200. Volts .018 Ampers

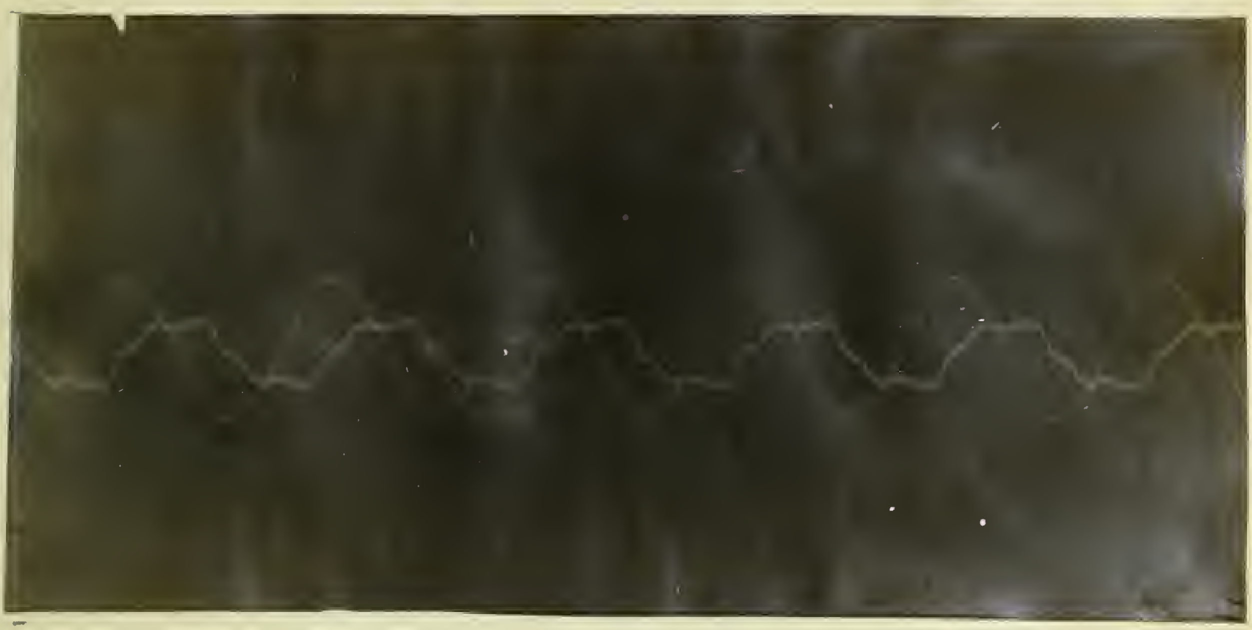


Height of Wire 10 Feet 3 Inches
68,300. Volts .02075 Ampers

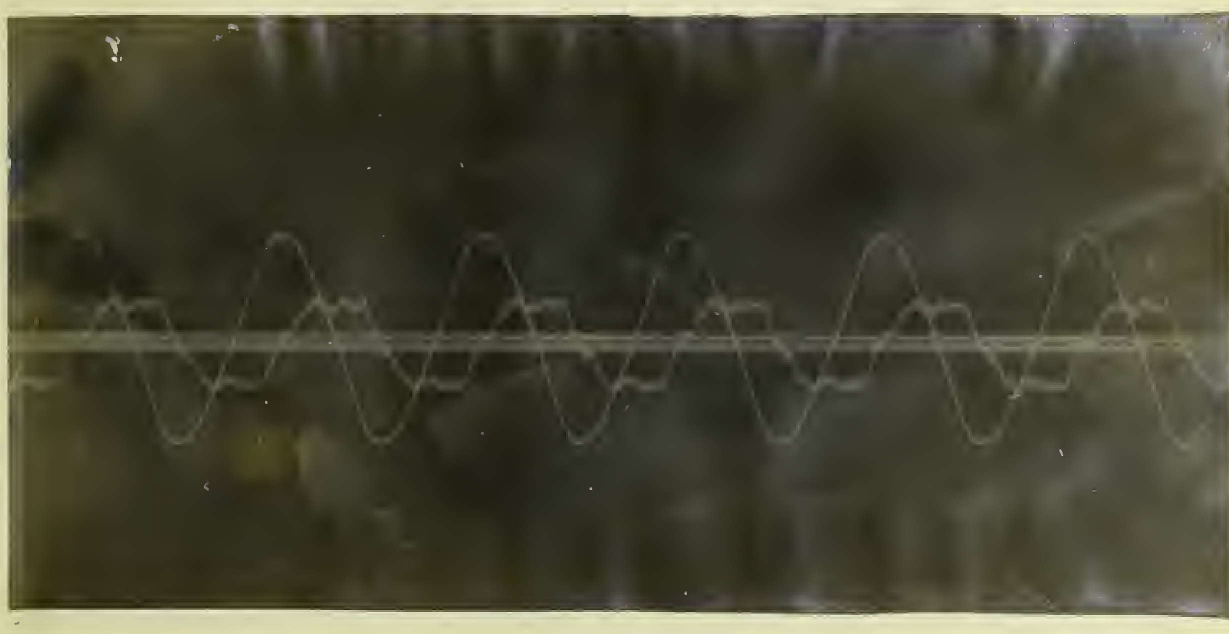
Height of Wire 10 Feet 3 Inches.
72,700 Volts .0215 Ampers.



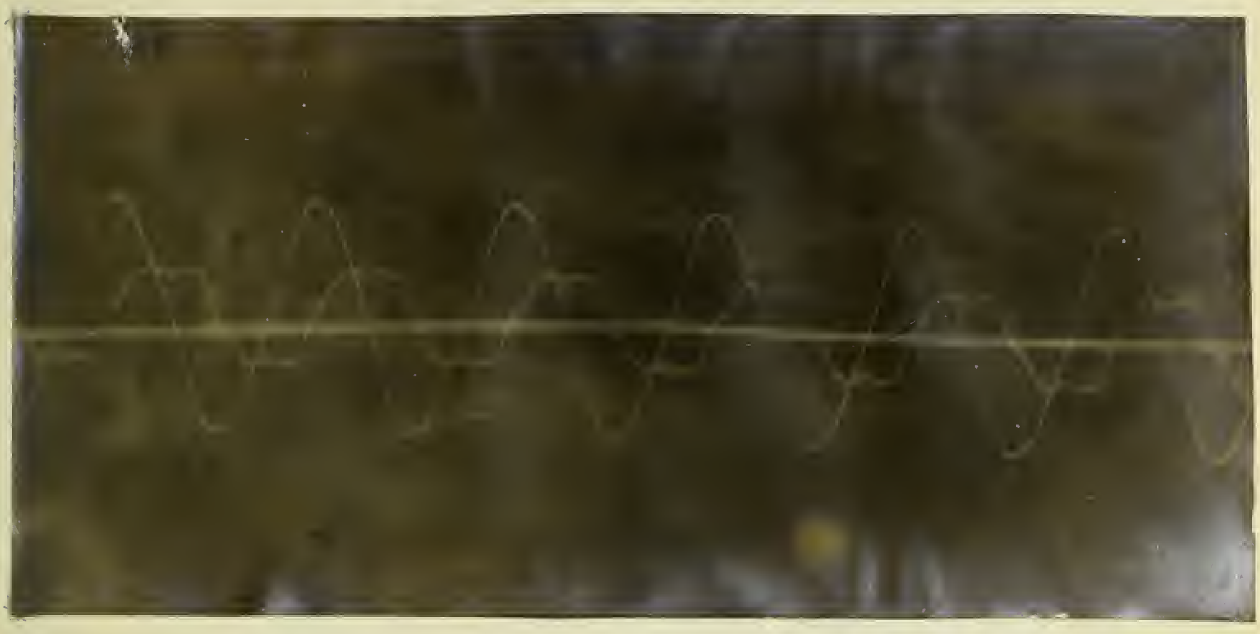
Wire Disconnected
45,500. Volts .007 Ampers



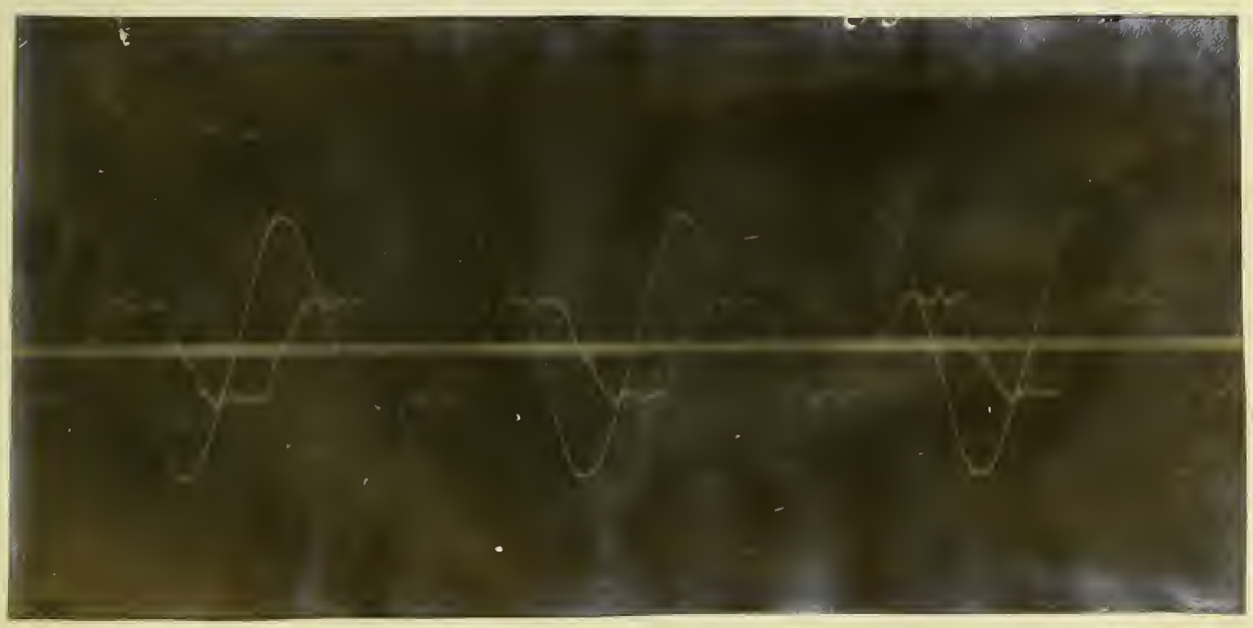
Wire Disconnected
59200. Volts .01125 Ampers

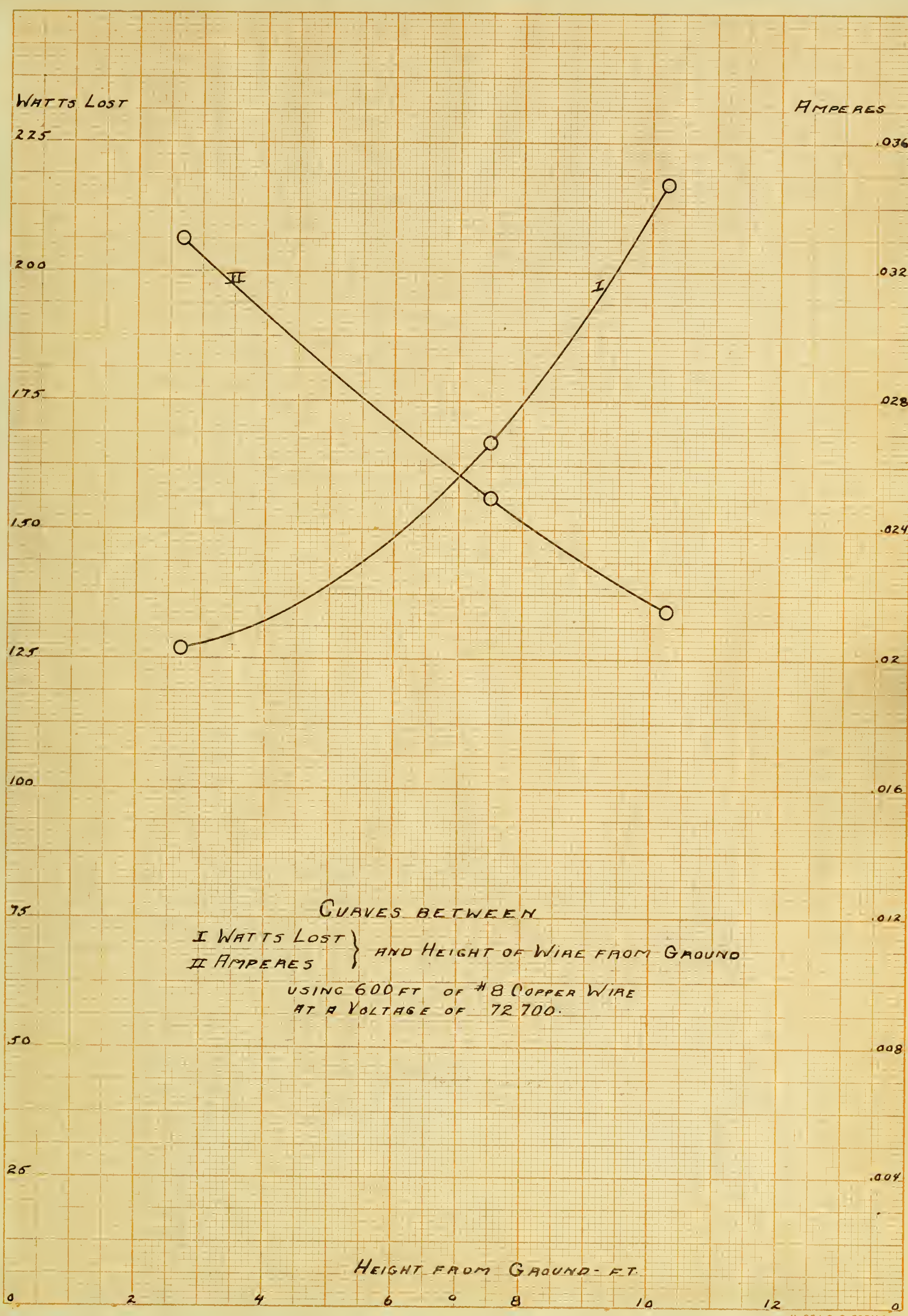


Wire Disconnected
68,300. Volts .01175 Ampers



Wire Disconnected
72,700 Volts .013 Ampers.




Watts Lost
Amperes
225
200
175
150
125
100
75
50
25
.036
.032
.028
.024
.02
.016
.012
.008
.004
0
I
II
Curves between
I Watts Lost
II Amperes
and Height of Wire from Ground
using 600 ft of #8 Copper Wire
at a Voltage of 72 700.
Height from Ground - ft.
0
2
4
6
8
10
12
0